A Twelve-Channel Carrier Telephone System for Open-Wire Lines

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A new carrier telephone system is described, together with its application in the long distance telephone plant. By its use, an open-wire pair which already furnishes one voice circuit and three carrier circuits may have twelve more telephone circuits added. Thus in all sixteen telephone circuits are obtained on a single pair. Several such systems may be operated on a pole line.

Various problems incident to the extension of the frequency range, from about 30 kilocycles, the highest frequency previously used, to above 140 kilocycles, are discussed. Among the more important of these are the control of crosstalk between several systems on a pole line, arrangements for taking care of intermediate and terminal cables, and automatic means for compensating for the effects of weather variations on the transmission over this wide frequency range.

Introduction

BARE wires supported on insulators, stretched between poles, make up the pioneer electrical communication circuit, the open-wire line. Although great advances have been made in the application of cable structures, the open-wire lines still hold their own in some sections of the country. This is because, to offset their physical vulnerability, they have several unique virtues. They are flexible and permit adding one pair of wires at a time. They are also comparatively economical where conditions favor their use. Furthermore, they are low-attenuation circuits and for this reason were the first to be used for high-frequency carrier systems.

The first carrier systems, beginning in 1918, added three or four channels to the existing voice circuit on a pair. To keep pace with this development, improvements in transposition systems were devised so that many such carrier systems might be operated on the same pole line. Such carrier systems, typified by the three-channel type C [1] system, have seen continuous growth in use in the long distance plant. Now a twelve-channel system, the type J, is being made

[1] "Carrier Systems on Long Distance Telephone Lines," H. A. Affel, C. S. Demarest and C. W. Green, *Bell System Technical Journal*, July 1928, and *A. I. E. E. Transactions*, Oct. 1928, pp. 1360–1387. "A New Three-Channel Carrier Telephone System," J. T. O'Leary, E. C. Blessing and J. W. Beyer, *Bell System Technical Journal*, this issue.

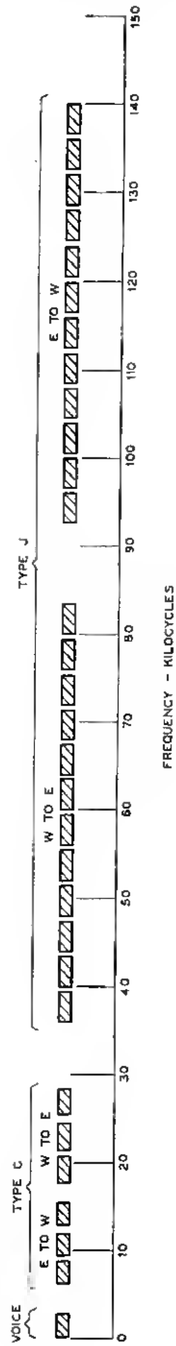


Fig. 1—Frequency allocations.

available to add to the type C system, thus giving sixteen telephone circuits on an open-wire pair in addition to the two telegraph circuits. Since there are already about 60,000 miles of pole line equipped with type C systems, the new type J system was developed to go in the frequency range above the type C system rather than to supersede it with more channels (Fig. 1).

The new system has been designed to meet high standards of transmission and reliability for distances up to several thousand miles. The frequency band transmitted by the individual derived circuits is exceptionally wide, from about 100 to 3600 cycles for a single system and has been previously discussed [2] in relation to the channel spacing in this and other new broad-band developments.

An important feature of the work on the type J system has naturally been that of making the line circuits suitable for carrying the higher frequencies. The tendency of circuits to crosstalk into one another increases rapidly with frequency. Advances in transposition design and structural improvements have now made it possible to extend the frequency range from 30,000 cycles to 140,000 cycles, which is about the upper frequency of the type J system. The problem of incidental cables in open-wire lines has also been serious, since the losses increase with frequency, and what is usually more important, there may be substantial reflection effects at junctions of the open-wire line and cable. These are serious, not only from the standpoint of the transmission loss which they entail, but from their effect on crosstalk. The increase in attenuation at the higher frequencies has also brought other problems into the picture. For example, repeaters are needed at more frequent intervals than with the lower frequency systems. Attenuation variation with frequency due to weather changes is greater than at the lower frequencies.

Figure 2 shows schematically the complete type J system, with its different major circuit elements, resulting at the terminals in the division of the single line circuit effectively into sixteen talking circuits. In no recent development is the function of the wave filter in providing essential units in a frequency dividing plan more forcefully illustrated than in the application of this new system, in combination with the type C and other facilities which exist. There are about sixty different designs of filters and networks in the terminals and repeaters. Their functions are varied,—as, for example, separating the individual channel bands, separating the opposite directional groups of channels, separating the type J frequency range as shown in Fig. 1 from the type C and other ranges, separating the different carrier frequencies

[2] "Transmitted Frequency Range for Circuits in Broad Band Systems," H. A. Affel, *Bell System Technical Journal*, October 1937.

of a carrier supply system in which the carriers are all derived from a common 4000-cycle source, etc.

The new system, as in the case of the type C, uses single sideband transmission with carrier elimination. Copper-oxide units are employed as translator elements of various kinds,—modulators, demodulators, and harmonic producers. Methods of mounting the equipment, and methods and apparatus for testing follow lines already worked out for the type K cable carrier system, which was described a year ago in two A. I. E. E. papers.[3]

Channel Terminals

A terminal of the type J system changes twelve independent voice channels into a compact block of twelve carrier channels properly allocated in frequency for transmission over the open-wire line. Inversely, such a block received from the open-wire line is separated and transformed into twelve independent voice channels. The first step in transmitting the twelve voice channels is to modulate them on twelve carrier frequencies 4 kilocycles apart from 64 to 108 kilocycles and to select the lower sidebands by means of quartz crystal channel band filters. The last step in the conversion from a received twelve-channel block to the twelve independent voice channels consists in the division of the block by twelve quartz crystal channel filters and the demodulation of these messages to produce voice frequency transmissions. These two frequency changes and separations are performed by the same equipment that is used in the type K cable carrier system terminals.

Figure 3 shows the circuit of a modulator and a demodulator for the opposite directions of a single conversation with indicated connections for the eleven others which make up this fundamental twelve-channel block. The modulator consists of a bridge assembly of copper-oxide varistors and is supplied with about 0.5 milliwatt of carrier power from the carrier supply system which is described later. Of the two resulting sidebands, the lower is selected by the crystal band filter following the modulator. The line sides of twelve modulator band filters are joined in parallel and a compensating network is connected to preserve the band characteristics of the upper and lower channels.

On the receiving side, after separation by one of the twelve parallel filters the sideband is applied to a demodulator supplied with the

[3] "A Carrier Telephone System for Toll Cables," C. W. Green and E. I. Green, *Bell System Technical Journal*, January 1938 and *Electrical Engineering*, May 1938. "Cable Carrier Telephone Terminals," R. W. Chesnut, L. M. Ilgenfritz and A. Kenner, *Bell System Technical Journal*, January 1938 and *Electrical Engineering*, May 1938.

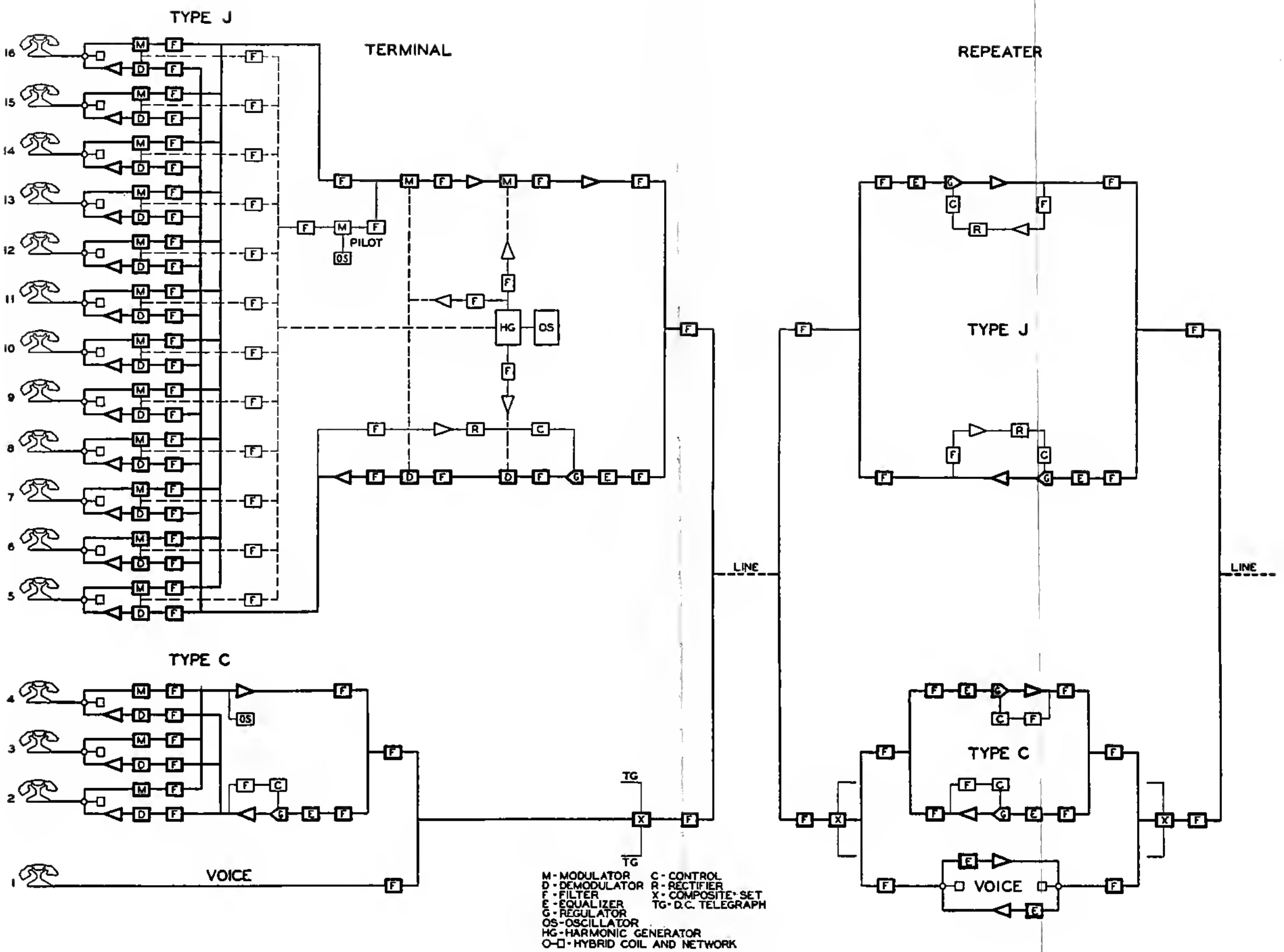


Fig. 2—Terminal and repeater layout.

proper carrier frequency to restore the voice frequency message. Because of the low level at which demodulation takes place, the demodulator is followed by a single-stage amplifier to produce the level desired in the voice frequency circuit. The gain of this amplifier is adjustable over a moderate range.

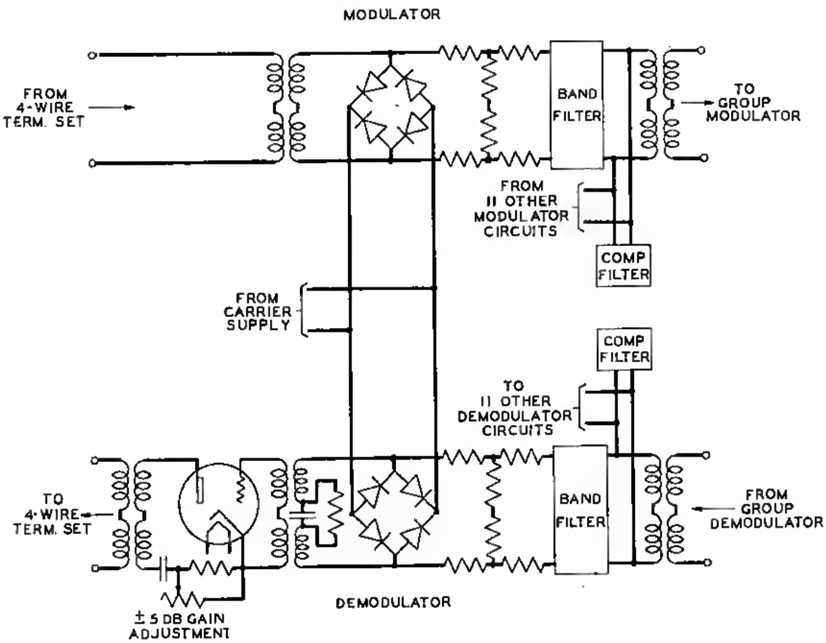


Fig. 3—Channel modulator and demodulator.

The combination of a single modulator and a single demodulator and associated equipment shown in Fig. 3 is called a "Modem" and two of these are mounted on a single equipment panel. Nine of these panels, sufficient for one and a half type J systems, or eighteen conversations, mount in a single relay rack bay of standard height.

Carrier Supply

The carrier frequencies 64–108 kilocycles are all derived as harmonics of a 4-kc frequency produced by a tuning fork controlled oscillator. This frequency is applied to an easily saturated coil to produce a sharply peaked wave which is rich in odd harmonics. Even harmonics of 4 kilocycles are obtained by rectification in a copper-oxide unit of part of the odd harmonic output. Odd and even harmonics appear in separate circuits from which each frequency desired is separated by a quartz crystal filter. Frequencies as high as the 121st

harmonic, that is, 484 kilocycles, are obtained in this way from the carrier supply system. Because of the importance of the carrier supply two sources are provided, with automatic equipment to transfer rapidly from the regular to the emergency source.

Group Modulation

As shown in Fig. 1, the type J system uses a band of 36 to 84 kilocycles for the west to east direction of transmission and 92 to 140 kilocycles for the east to west direction. The output of the fundamental twelve-channel unit consists of twelve lower sidebands from carriers of 64–108 kilocycles. This must, therefore, be translated to the two type J directional groups for line transmission. Since the frequencies in the fundamental unit overlap those in both directions of line transmission, this transfer must be made in two steps. Figure 4 shows these frequency translations. The first group modulation is the same for both directions of transmission. By modulating the fundamental unit with a carrier of 340 kilocycles there is obtained a block of lower sidebands extending from 400 to 448 kilocycles. A second modulation with a 484-kc carrier then gives, for transmission from west to east, a twelve-channel block of upper sidebands extending from 36 to 84 kilocycles. For the east to west transmission the second modulation uses a 308-kc carrier, producing a twelve-channel block of lower sidebands between 92 and 140 kilocycles.

Frequencies as high as 308, 340 and 484 kilocycles are chosen for group modulation in order that undesired products shall be well separated from desired products to permit their elimination by simple filter structures.

The same group modulation processes that have been described above for adapting the twelve-channel group for line transmission are used in the opposite sequence for receiving the block from the line and preparing it for separation by the channel band filters of the receiving terminal; thus, for instance, at an east terminal the block of upper sidebands, extending from 36 to 84 kilocycles as received from the line, is first modulated with 484 kilocycles producing lower sidebands between 400 and 448 kilocycles. These are next modulated with 340 kilocycles, which produces a block of twelve lower sidebands extending from 60 to 108 kilocycles, which is the group that the fundamental twelve-channel terminal unit is designed to handle.

Figure 5 shows the essential features of the group modulating and group demodulating circuits. As in the type K system, group modulation is performed at a very low level of the message material and with a high level, about 25 milliwatts, of the group carrier supply, in order

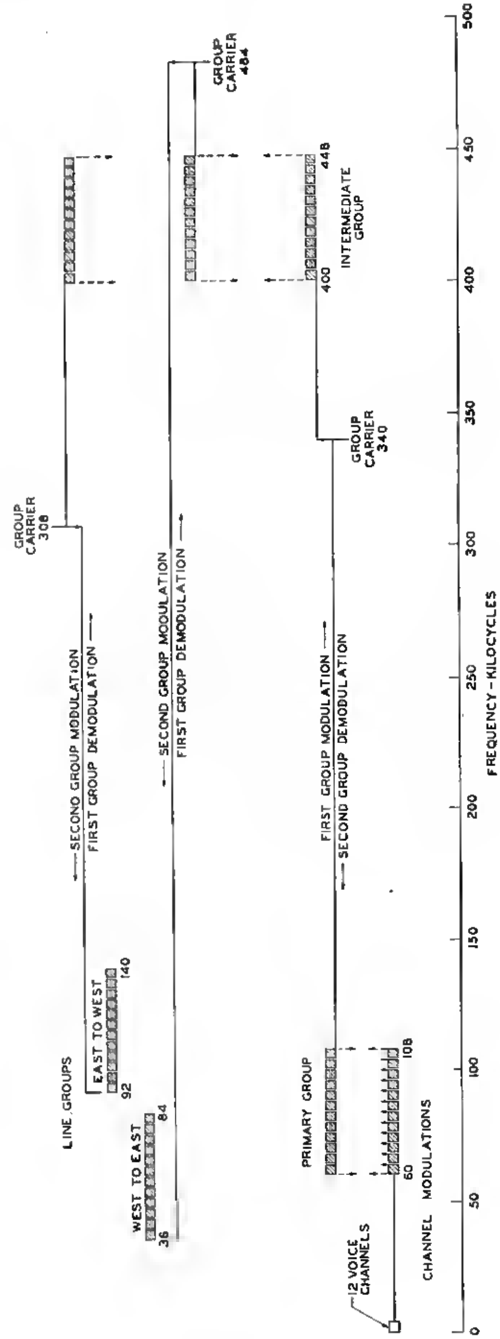


Fig. 4—Frequency translations.

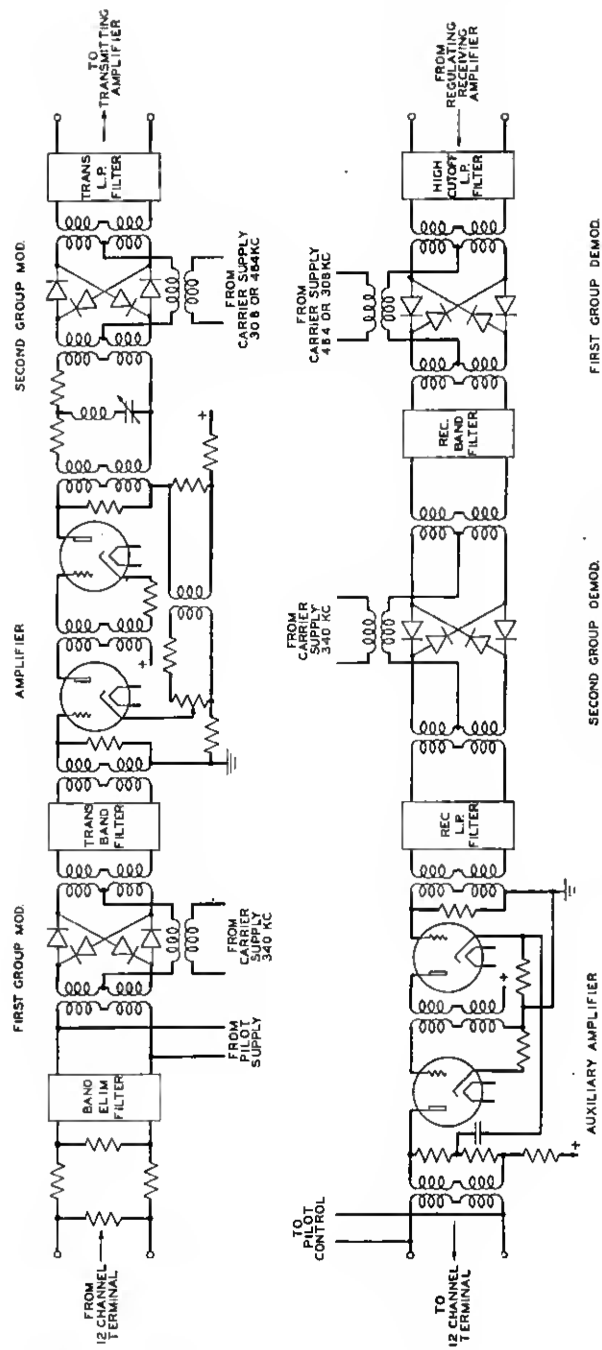


Fig. 5—Group modulator and demodulator.

to minimize interchannel crosstalk. The group modulators are of the doubly balanced bridge type which aids in suppressing some of the unwanted modulation products. Following the first group modulator and also following the first group demodulator are coil and condenser type 400–448 kc band filters which reject the unwanted products and pass the band of frequencies containing the twelve channels. Between this filter and the second group modulator on the transmitting side of the terminal, an intermediate amplifier is used in order to keep the level of the group transmission above danger of noise. Following the second group modulator and also following the second group demodulator are low-pass filters which cut off frequencies above about 160 kilocycles, to suppress unwanted modulation products. From the output of the receiving low-pass filter the twelve-channel group, 60–108 kilocycles, passes through a two-stage "auxiliary" amplifier to bring it to the desired level.

The carrier frequencies for group modulation and for group demodulation are derived from the same 4-kc tuning fork controlled oscillator that supplies carriers for the twelve-channel unit. From the circuit in which appear the odd harmonics of 4 kilocycles, the 77th, 85th and 121st harmonics, that is, 308, 340 and 484 kilocycles, are selected by carrier supply filters and separately amplified by two-stage amplifiers to produce the powers required for group modulation. Outputs from these amplifiers are fed to individual frequency busses capable of supplying the group modulators and demodulators for ten systems. An emergency carrier supply for these frequencies is also provided, with arrangements for switching rapidly from the regular to the emergency circuits.

Terminal Amplifiers

As indicated on Fig. 5, the transmitted twelve-channel group, now transferred to the proper frequency range for line transmission, goes from the low-pass filter at the output of the second group modulator to a transmitting terminal amplifier which is similar in most essentials to the amplifiers of the line repeaters. The twelve-channel group, arriving from the line, passes through a regulating amplifier arranged and controlled to compensate for variations in equivalent of the adjacent line section before passing to the first group demodulator. Similar regulating amplifiers are used at all repeater points.

Filters

At terminals and also at repeater points, two kinds of filter sets are required. One kind is used in the line to separate the type J

frequency range 36 to 140 kilocycles from the type C and other lower frequencies on the line. The second kind is the directional filters of the type J system itself. These separate a twelve-channel band of frequencies lying below 84 kilocycles used for west to east transmission from the twelve-channel group lying above 92 kilocycles which is transmitted from east to west. These directional filter sets are carefully designed to equalize any non-uniformity of loss in both the directional and the line filters. As this equalization involves a considerable loss over a large part of the filter band it is provided entirely in the receiving directional filters where the transmission is at a low level and the loss can readily be made up by amplification. In this way nearly the full energy output of the transmitting or repeater amplifier is available for line transmission.

Line Crosstalk Problems

As noted previously, type J systems will, in general, be applied on pairs on which type C systems are already operating. Such pairs have already been arranged to transmit frequencies up to 30,000 cycles, and transposed in such a manner as to perform satisfactorily as regards crosstalk to and from nearby pairs on which similar carrier systems are operating. In addition, on most modern lines the spacing between wires of a pair has been reduced from twelve to eight inches; and, on many of the lines, in order further to reduce crosstalk by increasing the spacing between pairs, the number of pairs on a crossarm has been limited to four instead of five, omitting the pole pair. Now, by applying a new transposition system designed for type J operation up to 140,000 cycles, an eight-inch spaced four-crossarm line may be arranged to transmit type J frequencies on at least ten pairs out of sixteen. Type C systems may, of course, be used on all of the pairs. Finally by using the most advanced transposition design methods, and increasing the crossarm spacing, in addition to the features noted above, a new line may be constructed to permit the operation of sixteen channels on all pairs.

To make the pairs of wires good for type J systems, more than a fourfold increase in frequency range, was difficult. The natural tendency of the circuits to crosstalk is increased even more than the frequency ratio, so that in addition to applying a new transposition design it is necessary that the transposition poles be more accurately located, and that the sags of the two wires of each pair be kept more nearly alike. On lines which already have eight-inch spaced wires, no major structural changes are necessary. However, on lines which have only twelve-inch spaced wires and where it is desired to make available a

number of pairs for type J transmission, structural changes, such as respacing the wires of the pairs concerned to six inches, are necessary in order to reduce the coupling.

One factor of extreme importance is that of reflected near-end crosstalk. In the application of transposition systems it is usually not possible to reduce the near-end crosstalk to a magnitude approximating the far-end crosstalk. It is the latter with which the carrier systems are chiefly concerned, since similar types of systems on different pairs all transmit the same frequency range in the same direction. If, however, the lines concerned do not have smooth impedance characteristics, i.e., a high degree of freedom from reflection effects, near-end crosstalk may be converted by reflection into far-end crosstalk of sufficient magnitude to be controlling over the true far-end crosstalk.

This means that lines to be used for several type J systems must be made unusually smooth electrically—impedance variations kept within a few per cent. The achievement of such smoothness consists chiefly in:

(1) Reducing the electromagnetic and electrostatic couplings to other pairs so that there are no large energy interactions, with corresponding impedance irregularities. Generally speaking, when the pairs concerned have been transposed for reduced far-end crosstalk up to the maximum frequency transmitted, this condition is also satisfied.

(2) Minimizing the effect of intermediate and terminal cables. This latter problem has caused considerable concern and is responsible for the development of several new techniques in the design and treatment of such cables, where they appear in a long line otherwise consisting chiefly of open wire.

Cable Treatment

As a means of overcoming the reflection and attenuation effects of short pieces of terminal or intermediate cable, loading naturally suggests itself, as applied in type C systems, where the cable pairs involved are commonly equipped with carrier loading coils, spaced at about 700-foot intervals. This compares with the 3000-foot or 6000-foot spacings which are standard for voice-frequency loading. However, loading pairs in existing cables satisfactorily up to 140,000 cycles would mean coils at approximately 200-foot intervals. Because of physical limitations, existing manhole spacings, etc., this is highly impractical. A reasonable solution has, however, been found in the creation of a new form of low-capacitance high-frequency cable,—a disc-insulated unit which has constructional features in common with the coaxial cables and a capacitance of only .025 microfarad per

mile as compared with about .062 microfarad for conventional cable pairs. This permits more practical loading coil spacings. These disc-insulated units are made up as spiral-fours, that is, two pairs (.051″ diameter wire) which form the diagonals of a square. When these cables are loaded with small coils at intervals of approximately

Fig. 6—Disc-insulated cable. Sheath diameter 2.3 inches.

600 feet, they present impedance characteristics substantially equivalent to that of an open-wire pair over the desired frequency range. Accordingly, they form a desirable, although somewhat expensive, solution of the problem of intermediate or entrance cables. As shown in Fig. 6, the spiral-four units are bound together in complements of seven or less under a lead cable sheath similar to standard toll cables. It should be noted that the low-capacity disc-insulated loaded cables not only provide a satisfactory solution of the impedance matching

problem, but they also give a cable circuit of low attenuation,—approximately 1.2 db per mile at 140 kilocycles.

Nevertheless, where spare pairs exist in cables, it has often been found economical to use them for type J transmission. It is possible to use them only non-loaded, in which case the attenuation is very high—4 to 6 db per mile, depending on the gauge, at 140 kilocycles, and impedance matching transformers are, of course, required at the junction of the open wire and cable. There are cases where this higher attenuation may be permitted and these pairs are used by separating the type J range from the lower frequency range, which is transmitted through pairs equipped with the older type C carrier loading. The separation is accomplished by filters which are usually housed in small filter huts at the junction of the open-wire line and cable.

In other cases it has been found economical to use the frequency separation method with filters and to install new non-loaded cables of lower attenuation to lead in the type J frequency band alone. Paper insulated 10-gauge pairs or the disc-insulated spiral-four cable of the type described above may be used for this purpose. In either case transformers are used to match the cable impedance to that of the open-wire line over the type J frequency range.

The reflection requirements are so severe and the effects of even short lengths of cable at the high frequencies so serious, that even short lead-in cables, where the open-wire line actually extends to the repeater or terminal building,—cables which are only 100 or 200 feet long, must receive special treatment. This has also been accomplished by the use of the disc-insulated spiral-four cables, loaded.

Interaction Crosstalk

Because of the higher attenuation there will be many repeater points on a long line at which the type J system will be amplified but at which the other systems and wires on the line will pass through the station without amplification. In this case, even though the type J pairs are properly transposed to keep down crosstalk between themselves, there still remains the crosstalk between them and the other pairs on the line, not only pair-to-pair crosstalk but crosstalk from the type J pair to various circuit paths consisting of irregular wire combinations.

Two difficulties arise in this case: The first is that the crosstalk from the output of one J system into an irregular path may be retransferred into the input of a repeater on another type J system. The second is that the crosstalk from the irregular path may be returned to the input of the same repeater and either influence the overall transmis-

sion characteristic or, if sufficiently severe, actually cause the repeater to sing. This general situation has made it necessary to introduce in the circuits at such points "crosstalk suppression" filters in the non-J pairs and longitudinal choke coils in all pairs.

Staggering

In addition to the various steps which are taken in order to reduce crosstalk by improving the line conditions, the type J system may include a feature which has been used in the type C system,—the staggering of the channel bands used on neighboring pairs. The advantage of staggering results from the facts that (*a*) the sensitivity of the ear and the power of the voice vary over the audible range, (*b*) the efficiencies of transmitter and receiver also tend to vary over the frequency range, (*c*) part of a channel band may lie opposite "dead" frequency range on an adjacent pair, and (*d*) by controlling the arrangement of the sidebands the crosstalk may be made unintelligible even if not inaudible. The staggering feature is readily provided in the type J system by a suitable choice of carrier frequency for the second group modulator and first group demodulator. With the staggered systems the highest frequency used would be about 143 kilocycles.

Attenuation Problem

In what has preceded in the discussion of line problems, the emphasis has been confined chiefly to the question of the smoothness of a line from an impedance standpoint in order to keep down reflection effects and, correspondingly, to improve the operation from a system-to-system crosstalk standpoint. There is also the problem of the higher attenuation incident to the use of higher frequencies. Between 30,000 cycles and 140,000 cycles, the normal wet weather attenuation for a 165-mil open-wire pair, for example, rises from about 0.13 to 0.28 db per mile,—an increase of approximately 2 : 1. Repeaters on the type J system, if applied on the basis of approximately the same output level and minimum level requirements, must be spaced at about one-half the interval of the type C systems. Normal spacings for type J systems would therefore be expected to range from 75 to perhaps 100 miles where no large amount of intermediate cable existed.

However, another problem, not present to a similar degree at the lower frequencies, tends in many cases to have a controlling effect on this spacing, that is, sleet or ice on the wires. With ice, frost, or snow on the wires, the wet weather attenuation may be exceeded by very large amounts. The additional attenuation is due primarily to the coating on the wires themselves rather than the coating on the

insulators. It arises from the potential gradient through the ice deposit in combination with the high dielectric loss characteristic of the ice or snow coating. Figure 7 gives examples of the attenuation

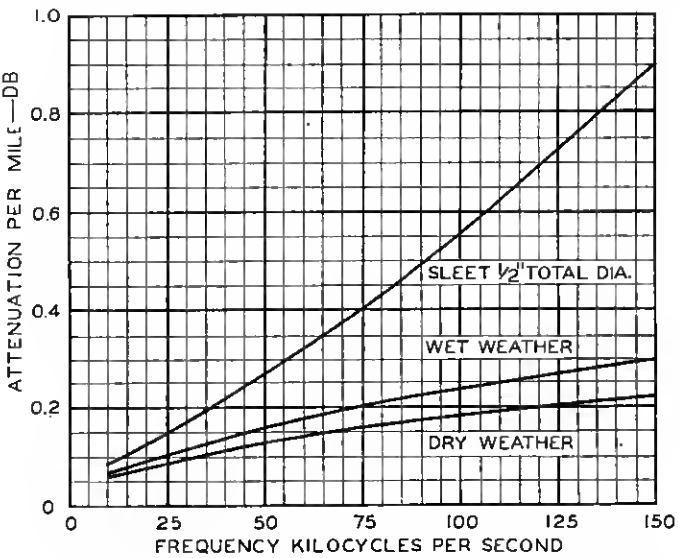


Fig. 7—Attenuation frequency characteristics of open wire lines.

frequency characteristics of open-wire lines, including certain measurements with ice coating. The exact increase in attenuation due to snow and ice naturally depends on the thickness and other characteristics of the coating. Even very thin coatings of ice on the wires tend to raise the attenuation at 140 kc from the normal wet weather figure of about 0.28 db to about 1 db a mile, i.e., an increase of three or four to one. Extremes up to 5 db per mile have been measured for short lengths of line with ice nearly two inches in diameter. Such heavy ice obviously approaches the mechanical breakdown conditions for the line.

Where ice and sleet occur the repeater spacings may be reduced to about fifty miles or less. The repeaters now being provided for the type J systems have gains of approximately 45 db. Repeaters are under development which are expected to raise the maximum available gain to something like 75 db. The normal dry or wet weather operation of such repeaters would be limited to gains of perhaps 10 to 25 db depending upon the amounts of cable included. The problem of obtaining automatic gain control over the extra wide range required by the high sleet attenuations is a difficult one.

Repeaters

At each repeater point line filters and directional filters are required on both sides of the amplifying equipment to separate type J currents from those of lower-frequency services on the line and to separate oppositely directed groups for separate amplification in one-way line amplifiers. These filters have been described in connection with the terminals where they perform similar functions. Two regulating amplifiers, one for each direction of transmission, properly controlled to compensate for variations in the attenuation of the preceding line section, are also needed at each repeater point. These are described later under "Regulation."

Figure 8 shows the circuit of one of the line repeaters and indicates the location of the directional filters, and certain supplementary filters for suppressing frequencies outside the transmitted range; also the regulating amplifier circuit, and the pick-off of the pilot channel which controls the gain.

The line amplifier has three stages of pentodes. The first two stages use single tubes of high voltage amplification and low power capacity while the third stage has four power pentodes in parallel to increase the output capacity. Because of considerable heat developed by these power tubes, special precautions are necessary to dissipate the heat and to protect condensers and other elements mounted near them.

Negative feedback to improve the operation of the amplifier is supplied over two paths. The inner feedback, from the plates of the output tubes over a properly designed network to the grid of the input tube, reduces the gain at frequencies outside the transmitted band and so prevents singing at those frequencies. It has little effect at frequencies within the type J range. The outer feedback path includes the input and output transformers, which are made as hybrid coils. In each of these one pair of the conjugate windings is connected to the incoming or outgoing circuit of the amplifier while the other pair is used for the feedback connection. By feeding back through the transformers in this way, they benefit by feedback in much the same way as the tubes, and the overall characteristic of the amplifier is practically independent of the transformer characteristics. This feedback reduces the amplifier gain by over 40 db and correspondingly reduces modulation effects within the amplifier, and gives exceptionally stable transmission with respect to tube and voltage changes. It is also designed to improve and stabilize the input and output impedances.

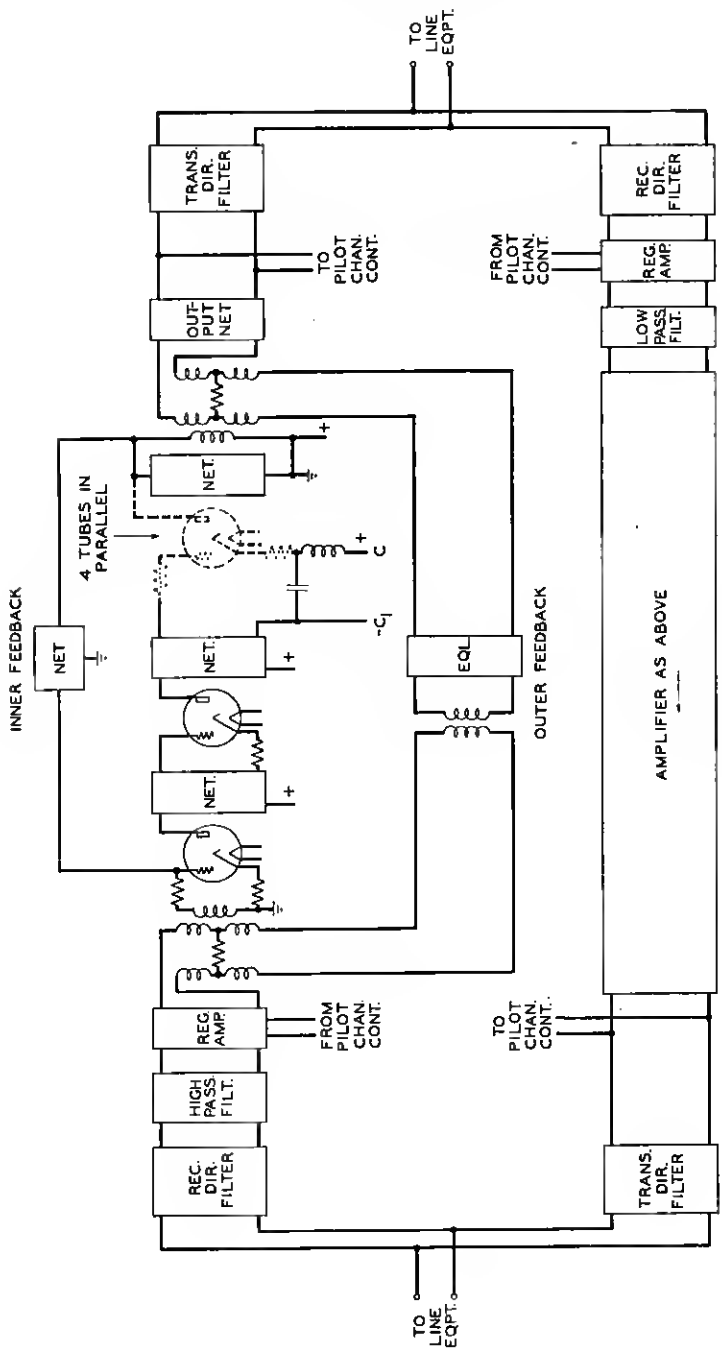


Fig. 8—Line repeater circuit.

Equalization

Equalization is necessary in each direction of transmission at a repeater point and in the receiving direction at a terminal, to compensate for frequency distortion produced by the preceding section of line. Fortunately, the attenuation frequency curves for the usual open-wire circuits, that is, 104, 128 and 165-mil wire, have nearly the same shapes for section lengths giving the same attenuation at the maximum frequencies for the two directions of transmission, so that these various circuits can be equalized alike.

As is well known, the transmission frequency characteristic of an amplifier with large feedback is almost the inverse of that of the feedback circuit itself, so that the insertion in the feedback circuit of a network having the same characteristics as a line section will provide equalized transmission over the amplifier and section combined. In the outer feedback circuit of the line repeater is included an equalizer which has a characteristic sloping with respect to frequency in the same way as the variation in loss under wet weather conditions of the longest open-wire section likely to be used. Thus, there is provided in the repeater a basic equalization for this longest wet weather line. At a receiving terminal a basic equalizer is provided which performs this same compensation, but in this case the slope of the curve must necessarily be opposite to that of the line attenuation and of the equalizer in the feedback path of the line repeater.

Line sections, however, vary in length and in the amount of entrance cable included. In order that they may be properly corrected by this basic equalization, they must be built out to equal this longest wet weather section. For this purpose there are provided flat loss pads and building-out networks whose losses have the same frequency shapes as the losses of short lengths of open-wire circuit. These pads and networks can be inserted or omitted by simple changes in strapping. They suffice to build out the shortest section which is expected to be used.

Pilot Currents

For a satisfactory system, arrangements must be provided to correct automatically for the effects on line attenuation due to changes in weather, by adjusting the amplification at each repeater point and in the receiving terminal circuit. To permit measuring these effects a pilot current of fixed frequency, near the middle of the transmitted band, and of constant amplitude, is supplied from each terminal. This is applied to the transmitting side of the terminal circuit between the twelve-channel terminal and the first group modulator, where the

message band lies between 60 and 108 kilocycles. The pilot frequency is 84.1 kilocycles which is obtained by modulation of 88 kilocycles, from one of the output taps of the channel supply of that frequency, with 3.9 kilocycles derived from a tuning fork oscillator. This modulation is performed in a copper-oxide bridge similar to the channel modulators and the desired product is selected by an 84-kc. carrier supply filter. The output of 84.1 kilocycles is sufficient to supply pilot current for ten terminals in the office. A sharply selective crystal band elimination filter is inserted between the output of the twelve-channel terminal and the point where the pilot source is bridged on the circuit to eliminate any current near the pilot frequency which would interfere with the small pilot current that is sent out to control the system.

The two group modulation processes alter this pilot frequency of 84.1 kilocycles so that it appears on the line as 59.9 kilocycles in the west to east directional band, and as 116.1 kilocycles in the east to west band. Correction in accordance with the magnitudes of these mid-group currents in the two directions is satisfactory over all twelve channels under ordinary conditions. In the case of ice or snow the channels at the edges of the directional frequency groups may not be properly adjusted. Additional pilot frequencies will probably be needed ultimately to care for such unusual conditions.

Regulating Amplifier

Figure 9 shows the circuit of the regulating amplifier, and above this, the circuit of the pilot channel receiving equipment which controls it. Current enters the regulating amplifier circuit from the left, coming from the receiving directional filter through a shielded transformer and the pads and building-out networks used for equalization. At the terminals the circuit includes also the basic equalizer. Last in the circuit leading from the line to the regulating amplifier is the regulating network which consists of a series of three equal networks having a total loss of 20 db at 140 kilocycles in the east to west direction and 15 db at 84 kilocycles in the west to east direction. The network loss increases with frequency in the same way as the difference between dry and wet weather attenuation of the line. The two terminals of the regulating network and the two junction points between the three networks are brought to four sets of stator plates on an adjustable condenser. The rotor of this condenser, which has about the same area as one set of stator plates, is connected to the grid in the first stage of the regulating amplifier. Rotation of the condenser therefore applies, to the grid of the first tube, a voltage which decreases continuously as the condenser rotates from left to right.

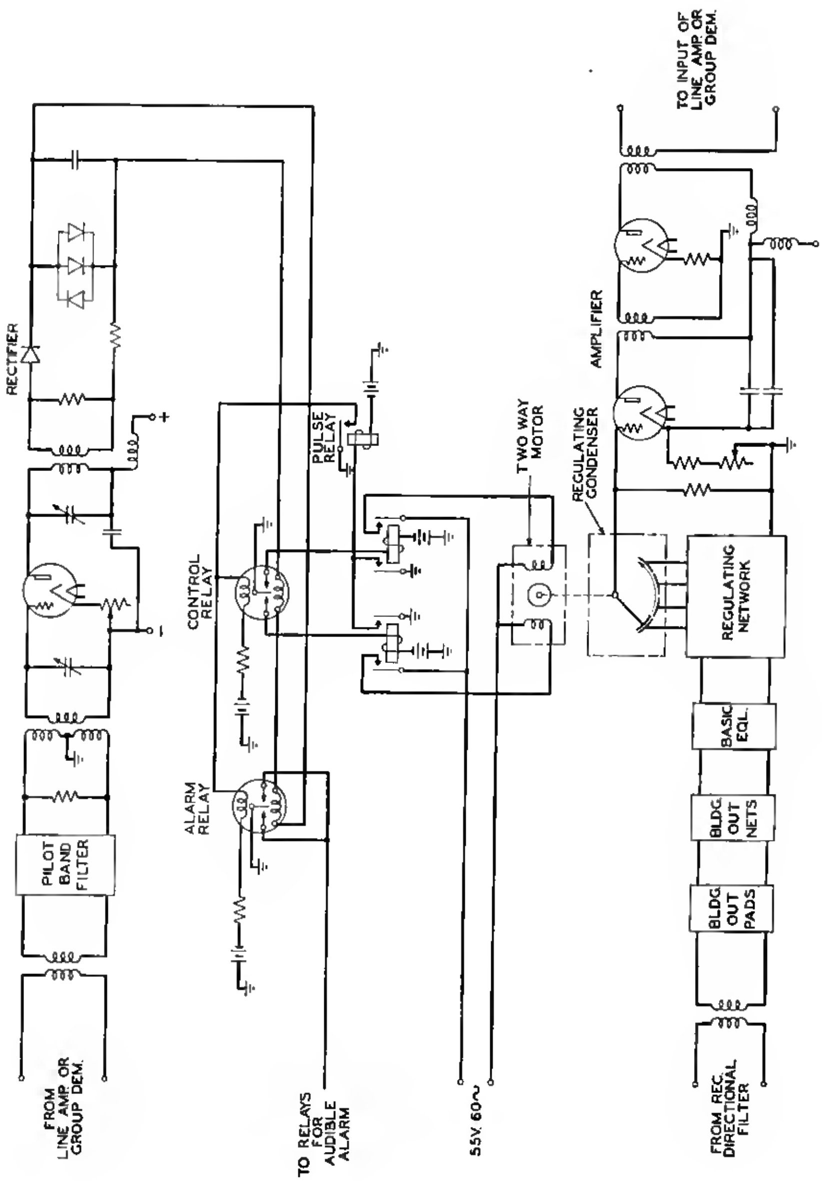


Fig. 9—Regulating amplifier and pilot control.

The regulating amplifier has two stages of pentode tubes, a high input impedance necessary for the proper operation of the condenser potentiometer, and feedback to stabilize the gain and to prevent intermodulation of the channels. Its output goes to the line amplifier at repeater stations, and to the first group demodulator at the terminals. At a west terminal there is interposed a high cut-off filter to eliminate frequencies above the upper band which may have been picked up on the open-wire line.

Pilot Control

The setting of the condenser which controls the regulating network is determined in accordance with the amount of pilot current flowing in the circuit in the direction concerned. At repeater stations the pilot current is picked off at the output of the line amplifier, being separated from the message transmissions by a quartz filter which has about a 30-cycle pass band. For control of transmission from west to east at the repeater stations, this filter selects 59.9 kilocycles and for control of the oppositely directed transmission, 116.1 kilocycles. At the terminals the pilot channel selecting filter is connected across the output of the auxiliary amplifier following the second group demodulator where the pilot frequency is 84.1 kilocycles. The pilot current from the pick-off filter is amplified in a single-stage amplifier which has feedback for constancy of operation and input and output circuits tuned to the pilot frequency. After amplification the pilot current is rectified by a temperature compensated copper-oxide rectifier.

The resulting direct current passes through the operating windings of the control and alarm relays. These Weston Sensitrol relays are, in fact, microammeters with high and low contacts made by the pointers. The mechanical bias of the moving system is adjusted so that with the normal pilot current the pointer will remain free in the middle between the two contacts. A change of about 0.5 db in this current will cause the pointer of the control relay to make contact with the terminal at the corresponding end of its swing. As the limiting contacts are magnetized and the pointer is of magnetic material, good contact is insured. When contact is made on one side a 60-cycle circuit is closed through the motor which controls the regulating condenser in such a direction as to cause the loss in the regulating network to be increased. Closure of the other contact similarly causes the loss in the regulating network to be decreased. Closure of either contact also closes a circuit containing a slow-operate "pulse" relay to release the Sensitrol relays after an interval of about four seconds. During this time the gain of the regulating amplifier will have been

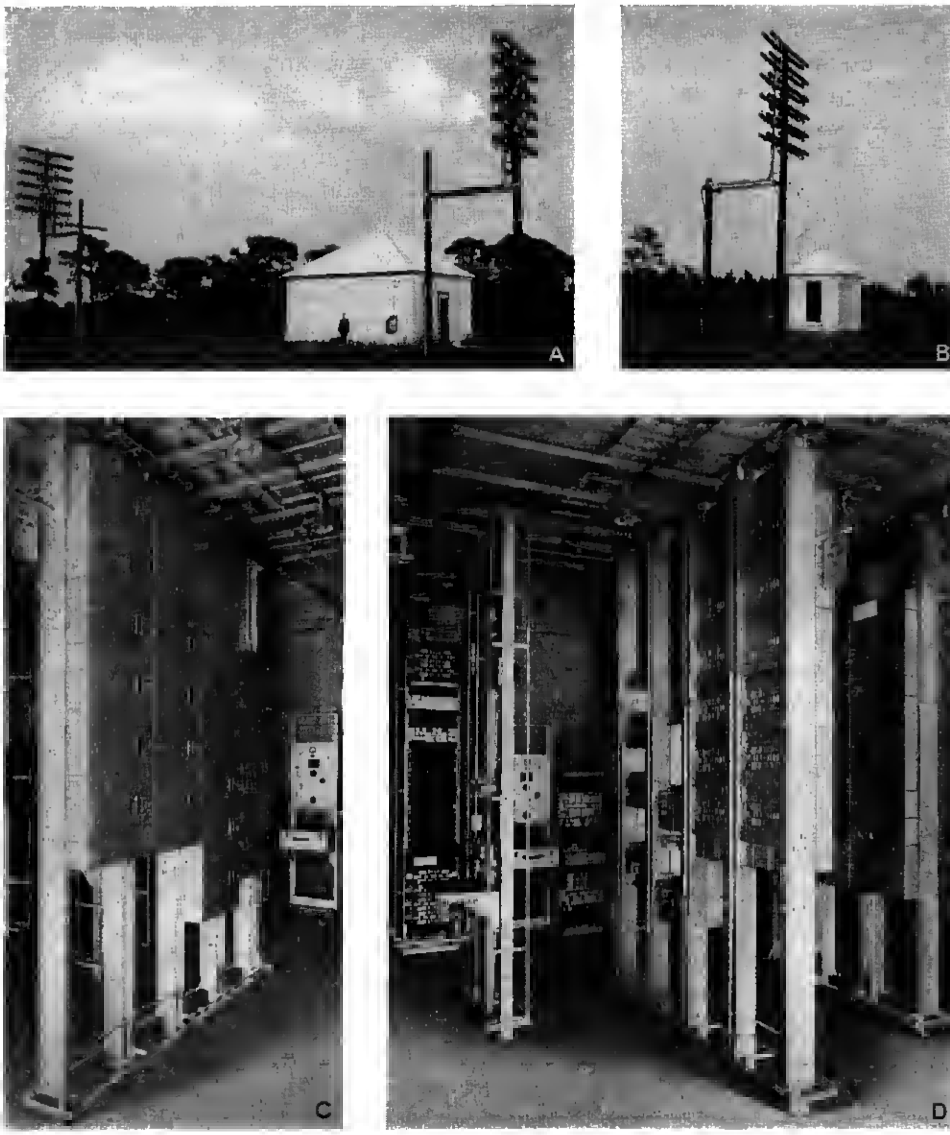
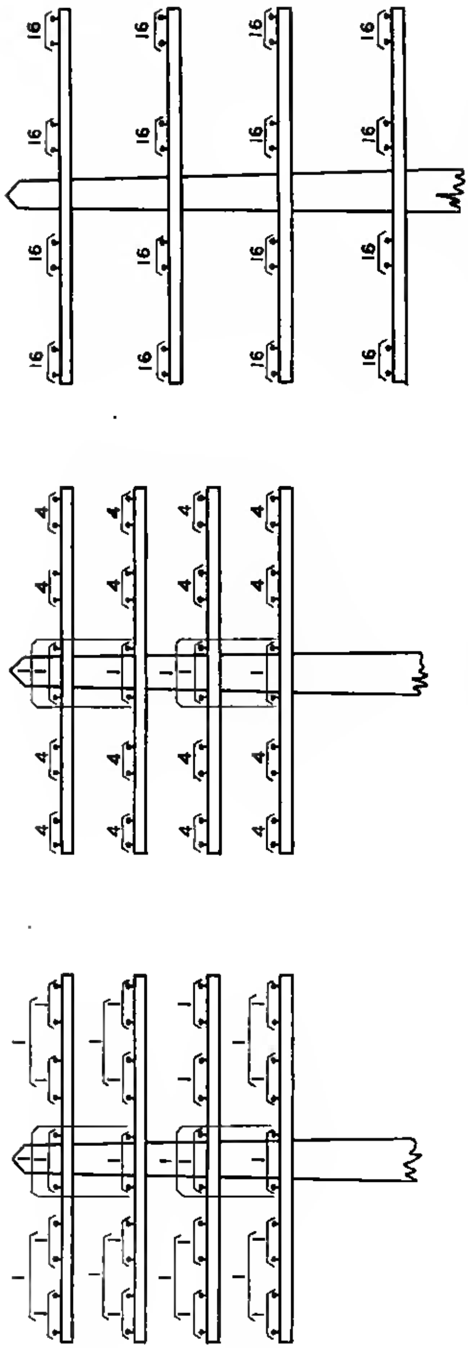


Fig. 10—Typical installations.
(A) Auxiliary repeater station.
(B) Cable hut.
(C) and (D) Terminal installations.



Facilities—30 voice circuits.

Line construction with 8″ spaced non-phantomed non-pole pairs. Type C systems on all 8″ spaced pairs. Facilities—22 voice circuits, 48 carrier circuits, total, 70

New line construction all 8″ spaced pairs, no pole pairs, crossarms spaced 36 inches instead of 24 inches. No phantoms. Facilities—16 voice circuits, 240 carrier circuits, total, 256

Fig. 11—Growth in line carrying capacity.

changed about 0.1 db. If now the pilot current level is within 0.5 db of normal the operation is complete. If not, it is repeated and the device keeps periodically testing the circuit so long as it is away from satisfactory compensation. There are also alarm circuits for attracting attention in cases of wide variations in equivalent. In severe ice conditions where a single regulating repeater has not sufficient gain to make up for the great loss in the line, the next succeeding repeater will do its utmost to make up the deficiency.

Conclusion

In what has preceded, developments have been described which are making it possible to provide a very substantial increase in circuits on open-wire pole lines without additional wire stringing. Photographs showing typical office installations of type J carrier equipment, unattended repeater stations, and filter huts are shown in Fig. 10.

Three stages in the development of the open-wire line over the past twenty years, giving successive increases in circuit capacity, are shown in Fig. 11. Prior to the application of carrier systems, a four-crossarm pole line would yield thirty voice circuits. Now, on a new line 256 circuits are potentially obtainable. Thus it is probable that the open-wire line will continue as an important factor in furnishing facilities in moderate numbers, particularly in the less densely populated sections of the country and where climatic conditions are not unfavorable. Installations of type J systems have already been made in various parts of the country.